Diurnal Variations in Cloud Structure Determined from CALIPSO and ICESat Lidar Data

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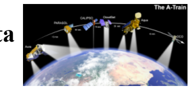


1.Instruction

Knowing the presence & vertical distribution of clouds is critical for understanding the relationship between clouds, the hydrological cycle, and the Earth-atmosphere system radiation budget. Accurate characterization of the vertical distribution of clouds is also needed to assess the clouds produced by general circulation models at all times of day. The vertical structure of clouds is an important component of cloud characterization because it affects the diabatic heating of the atmosphere and distribution of water. Satellite-borne lidars can measure the vertical distribution of clouds at greater detail than ever before possible. The Ice, Cloud, and Land Elevation Satellite (ICESat) Geoscience Laser Altimeter System (GLAS) measures cloud heights globally in a precessing orbit that permits viewing at different times of day each month. The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite (CALIPSO) with the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) is in a Sun-synchronous orbit with an equatorial crossing time of 1330 LT. GLAS and CALIOP measure clouds with similar sensitivities. By analyzing data from both satellites during a given period, it should be possible to determine the average diurnal changes in cloud structure on the large scale. Here, GLAS and CALIOP data taken during June 2006, October-November 2006, and March-April 2007 are analyzed separately for each day & night overpass on a regional basis to characterize the frequency of occurrence of both single and multilayered clouds at a given time of day. The June data were taken at nearly the same local times for both ICESat and CALIPSO, while the autumn measurements were taken nearly 6 hours apart. The spring measurements were separated by 3- 4 hours. Thus, it is possible to determine the similarities in the two cloud detection algorithms for each instrument to provide a baseline for characterizing the diurnal changes using the fall and spring datasets. Since GLAS has only measured clouds with the 1064-nm lidar since the beginning of 2004, it is first necessary to characterize the differences in GLAS cloud amounts derived from 532 and 1064 nm. The results shown here are a preliminary comparison of GLAS & CALIPSO clouds.

2. Data

GLAS level 2 middle resolution cloud layer heights (GLA09) determined from 1064 and 532nm (if available) channels are used:

- ✓ Sept 25 - Nov 18, 2003, both 1064 nm and 532 nm cloud layer height
- ✓ May 24 - Jun 26, 2006 **(0010/1300 LT)**
- ✓ Oct 25 - Nov 27, 2006 **(0800/2000 LT)**
- ✓ Mar 12 - Apr 14, 2007 **(0400/1600 LT)**

CALIPSO level 2 5km cloud layer heights are used:

- ✓ Jun 16 - Jun 26, 2006 **(0130/1330 LT)**
- ✓ Oct 25 - Oct 30 & Nov 14 - Nov 27, 2006
- ✓ Mar 12 - Apr 14, 2007

3. Results

3.1 Comparison between GLAS 1064 nm and 532 nm for Sept-Nov 2003

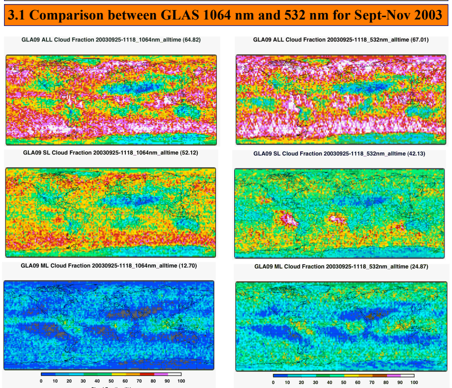


Fig. 1 Comparison of global cloud fraction of all clouds (top panels), single layer (SL) clouds (middle panels) and multi-layer (ML) clouds (lower panels) between 1064 nm (left panels) and 532 nm (right panels) for Sept-Nov 2003.

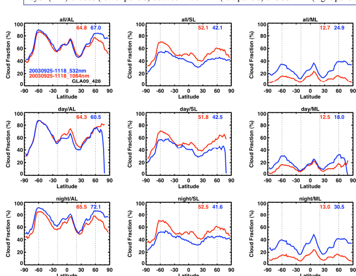
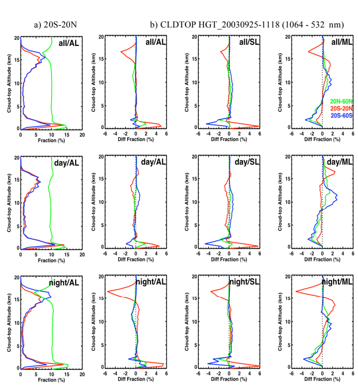


Fig. 2. Zonal mean cloud fractions for all clouds, single layer clouds, & multi-layer clouds for all times, day, and night from 1064 and 532 nm for Sept-Nov 2003.

- ▪ Overall, 532 nm detects slightly more (2%) clouds, especially over north polar region;
- ▪ Daytime 1064-nm CF is ~10% greater than 532nm CF in Tropics and ~10% less at night everywhere, except northern subtropics
- ▪ 532 nm detects more (12%) ML clouds than 1064 nm, especially at night;
- ▪ 1064 nm detects more (10%) SL clouds during day and at night
- ▪ During day, 1064 nm has similar sensitivity as 532 for ML in Tropics (20N-20S);



- During day time, the 1064 nm detects more (6%) low SL cloud but 4% less high SL cloud in the tropics;
- 1064 nm detects 2 - 5% less low SL cloud over the northern and southern mid-latitude regions; presumably due to diminished sensitivity

Fig. 3. Vertical distributions of **(a)** GLAS cloud top height frequency in Tropics (20S -20N), Sept-Nov 2003. Green lines are differences between 1064 and 532-nm plus 10% (for plotting purposes), **(b)** Vertical distribution of GLAS cloud-top height frequency differences from 1064 and 532 nm , Sept-Nov 2003.

3.2 Comparison of Cloud Fraction between CALIPSO and GLAS

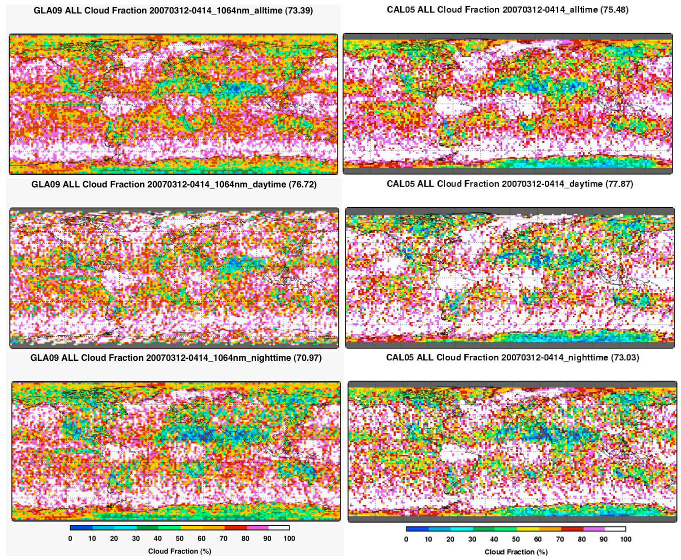


Fig. 4. Cloud fraction distributions from GLAS 1064 nm and CALIPSO for all times (top panels), day (middle panels) and night (lower panels) during Spring (Mar 12-Apr 14) 2007.

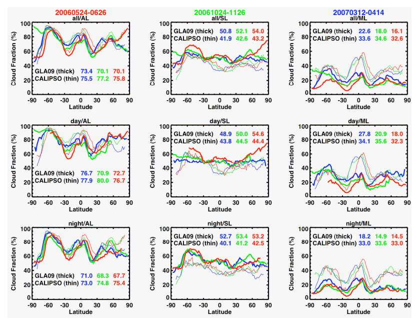


Fig. 5. Zonal mean all, SL and ML cloud fractions from CALIPSO (thin lines) & GLAS (thick lines) for the summer 2006 (red) , fall 2006 (green) and spring 2007 (blue).

Table 1 Global mean cloud fraction

AL	CALIPSO			GLAS (1064nm)		
	Day	Night	Total	Day	Night	Total
Mar 07	77.9	73	75.5	76.7	71.0	73.4
Jun 06	76.7	75.4	75.8	72.7	67.7	70.1
Oct 06	80.0	74.8	77.2	70.9	68.3	70.1
Oct 03				64.3	65.5	64.8

SL	CALIPSO			GLAS (1064nm)		
	Day	Night	Total	Day	Night	Total
Mar 07	43.8	40.1	41.9	48.9	52.7	50.8
Jun 06	44.4	42.5	43.2	54.6	53.2	54
Oct 06	44.5	41.2	42.6	50	53.4	52
Oct 03				51.8	52.5	52.1

ML	CALIPSO			GLAS (1064nm)		
	Day	Night	Total	Day	Night	Total
Mar 07	34.1	33	33.6	27.8	18.2	22.6
Jun 06	32.3	33	32.6	18	14.5	16.1
Oct 06	35.6	33.6	34.6	20.9	14.9	18
Oct 03				12.5	13.0	12.7

- For total cloud, CALIPSO detects more clouds in Tropics than GLAS for both day and night
- CALIPSO detects more ML cloud, less SL cloud than GLAS does both day and night due to GLAS 1064-nm retrieval being less sensitive than CALIPSO ("sees" through fewer clouds to next layer)

- Magnitude of differences between CALIPSO & GLAS for all cases in Mar 2007 similar to 532 & 1064-nm differences in Oct 2003. CALIPSO has 2% more total CF than GLAS, 10% less SL, 10% more ML.
- Overall, CALIPSO detects more ML (both day and night) than GLAS
- GLAS AL CF for Oct 03 is 5-9% less than for 2006/2007; this difference needs further study

3.3 Comparison of Cloud Top Height between CALIPSO and GLAS

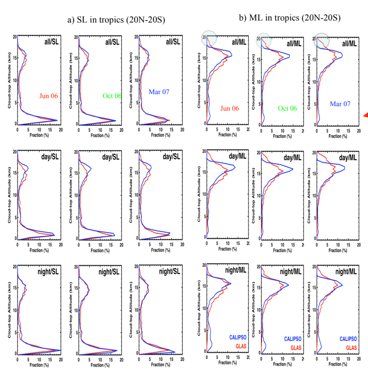


Fig. 6. Vertical distributions of cloud-top height from CALIPSO (blue lines) & GLAS (red lines) for (a) single- & (b) multi-layer clouds, June & Oct 2006 and Mar 2007 in Tropics.

- GLAS (in red) detects more cirrus above 18km; a false cloud artifact of current algorithm that worsens with time (note the shaded circles)
- CALIPSO detects more ML cloud than GLAS, especially during daytime; similar to 532/1064 results
- Most of upper-layer cloud top height in ML > 10 km; max is at 17 km which may be due to higher tropopause height in the tropics

In mid-latitude of NH (Fig 7a) and SH (Fig 7b),
- the max upper layer cloud top height for ML clouds is about 10-12km for CALIPSO;
- GLAS detects more upper layer cloud than CALIPSO above 12km in ML because of false cloud artifact in current algorithm that increases with time

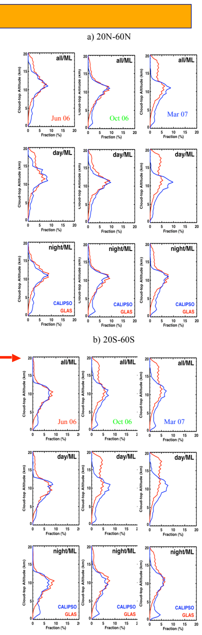


Fig. 7. Vertical distributions of cloud-top height from CALIPSO (blue lines) & GLAS (red lines) for multi-layer clouds, Jun & Oct 2006 and Mar 2007 for **(a)** NH 20N-60N and **(b)** SH 20S-60S .

4. Conclusions and Discussion

From GLAS Sept-Nov 2003 data analysis, it is found that

- ▪ GLAS 532 nm detects 2% more total cloud fraction than 1064 nm, especially over north polar region
- ▪ 1064 nm daytime CF ~10% > 532-nm CF in Tropics but night CF ~10% less everywhere but northern subtropics
- ▪ GLAS 532 nm detects 12% more ML clouds than 1064, especially at night, &10% less SL clouds both day and night

From GLAS and CALIPSO comparisons for 3 different months, it is found that:

- ▪ CALIPSO detects 75 to 77% total cloud fraction, which is about 2-7 % more than GLAS 1064 nm detected
- ▪ GLAS 1064nm CF in Jun, Oct 2006 and Mar 2007 is 5 to 8% higher than Oct 2003, especially more daytime ML clouds detected from GLAS 1064 nm; possibly due to false high cloud detection
- ▪ CALIPSO detects 50-100% more multilayered clouds than GLAS 1064 nm does
- ▪ CALIPSO has higher cloud top height in the tropics than GLAS; 1064-nm less sensitive to thinnest high clouds
- ▪ Most upper layer cloud top height for ML clouds is about 16 km for CALIPSO in Tropics & 10-12 km outside of tropics but extends more higher for the GLAS 1064nm. Algorithm produces false clouds in later series of 1064-nm data due to variations in GLAS laser energies each month. False returns increase with time.

Conclusions & Future Research

- GLAS cannot be used with CALIPSO to study diurnal variations because of 1064-nm reduced sensitivity & false returns
- Refinement of 1064-nm algorithms may produce cloud distributions that are consistent with CALIPSO
- Need to understand optical depth sensitivity differences between GLAS and CALIPSO

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